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# Implementation of a Microcomputer-Modified Electrical Aerosol Analyzer

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# Implementation of a Microcomputer-Modified Electrical Aerosol Analyzer

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Details of the system assembly and instructions for its operation are given. The appendices contain a flow chart and documented listing of Program EAA, the microcomputer program which operates the system.

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# IMPLEMENTATION OF A MICROCOMPUTER-MODIFIED ELECTRICAL AEROSOL ANALYZER

by

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## ABSTRACT

A commercial electrical aerosol analyzer has been modified through addition of a digital voltmeter, a microcomputer and a printer. In unattended operation the system can acquire a differential particle size distribution, print and plot the resulting spectrum in any of three possible representations, and repeat the cycle at preselected intervals.

Details of the system assembly and instructions for its operation are given. The appendices contain a flow chart and documented listing of Program EAA, the microcomputer program which operates the system.

This reports covers a period from March 1978 to March 1979, and work was completed as of March 31, 1979.

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# SECTION 1

# INTRODUCTION

The electrical aerosol analyzer (EAA) has become a popular instrument for measuring submicron aerosol size distributions since its commercial introduction in 1967. By exploiting the known dependence of electrical mobility on particle size, such instruments permit the real time measurement of aerosol particle size over at least 2 decades of the range below 1 μm. While the importance of the EAA to aerosol studies is well recognized, certain features of the EAA remain to be improved. Of particular concern in the present commercial version (Model 3030, TSI, Inc.) is the need for an operator to manually record the sequence of electrical currents produced during the instrument's measurement cycle, and then to perform a series of arithmetical steps which convert the currents to the corresponding aerosol size spectrum.

To solve this limitation the EAA could be supplemented with a minicomputer and related peripherals to perform data input, reduction and output functions. Such a system, however, is relatively expensive and less portable than may be desired. In the following we show how the same objective can be accomplished at much less expense by means of a microcomputer-based addition to the EAA. The addition consists of unmodified commercial components, including a $180 microcomputer, a digital voltmeter, a teletypewriter or equivalent, and an optional audio cassette recorder. (A well-equipped laboratory may already possess some of these instruments.) In unattended operation the resulting system is able to (1) acquire a differential size distribution over 10 intervals of equal logarithmic size between 0.0032 and 1 μm diameter; (2) print and plot the distribution directly in a number, surface or volume representation; and (3) repeat the cycle indefinitely at a selectable frequency.

A condensed description of the system described in this report is available elsewhere (Lewis 1979). The material in Sections 3 and 4 and in the Appendices of the present report has not been published previously, and contains those details required to actually implement and operate the microcomputer-modified system.

## SECTION 2

## SYSTEM DESCRIPTION

### HARDWARE

A block diagram of the assembled system is shown in Figure 1. The unmodified EAA consists of the two components shown within the dashed box -- the aerosol analyzer itself and its control module. In operation the control module causes the analyzer to generate a fixed time sequence of internal electric fields during a 2-min cycle. Aerosol entering the analyzer first becomes electrically charged and then is subjected to the particular electric field present at the time of passage. Depending on the magnitude of the electric field, only those aerosol particles larger than a minimum size are able to pass through the analyzer and contribute to a measurable aerosol current ("analyzer current"). Normally the control module is the component that measures the analyzer current sequence (whose values constitute the basic data output of the EAA) and presents the measured values visually to the operator. In the modified system, however, the current measuring and recording functions are performed by the additional components shown in Figure 1 outside the dashed box. Each of these components is described below.

#### Digital Voltmeter

The analyzer currents, available at an external coaxial connector on the EAA, are fed directly to the input of a laboratory digital voltmeter (DVM). (Although the signal of interest is referred to as a current, the EAA actually converts it internally to a voltage.) The DVM is conventional in all respects, but it must have the following capabilities (1) a resolution of at least 3½ digits, with a full scale reading of at least ±1 volt, and (2) a binary coded decimal (BCD) output, generating normal TTL positive-true voltage levels. The BCD output is a common interface type provided by some DVM manufacturers as an option for their instruments. Unfortunately, the DVM used in the EAA control module does not have this capability, resulting in the need for the additional DVM discussed here. Because of availability, the particular instrument used in this study was the 5½ digit multimeter Cimron Model DMM51 (California Instruments, Inc.).

#### Microcomputer

A KIM-1 microcomputer (Commodore/MOS, Inc.) was used to control the following: acquisition of analyzer currents from the DVM, arithmetical manipulation of the current values, and output of the computed aerosol

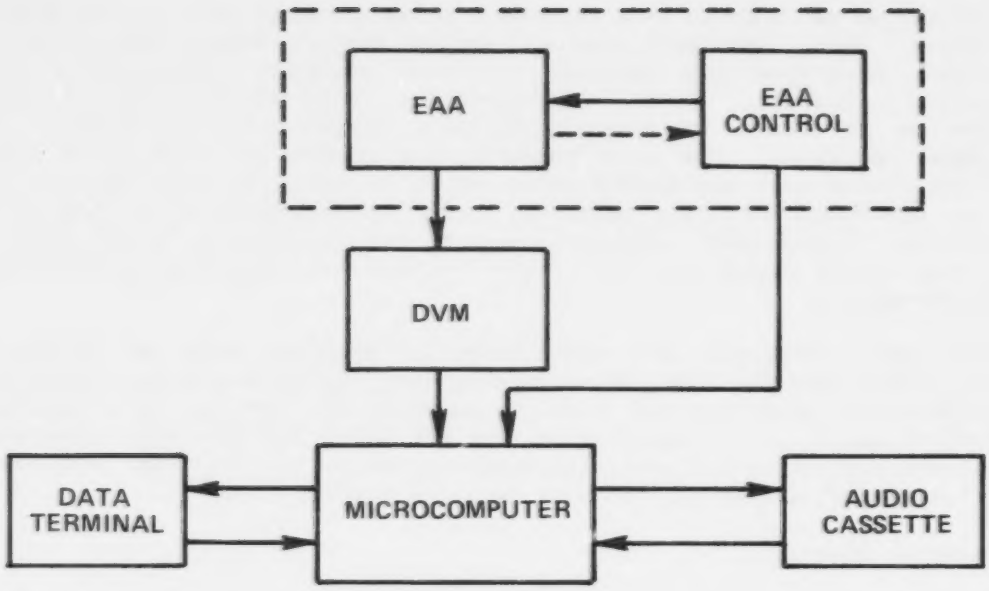


Figure 1. Aerosol system block diagram.

size distribution spectrum. The KIM-1 comprises all the elements of a full-fledged computer (a central processing unit, memory, and input/output interface circuitry), assembled on a single 21- by 26-cm printed circuit board. Details of the microcomputer have been described in earlier work (Lewis and Lamothe 1978).

### Data Terminal

A serial 20-mA current loop interface is an integral part of the KIM-1 microcomputer. Thus, the most obvious choice for an output device is a conventional teletypewriter because of its frequent availability in laboratories. However, newer teletypewriter "equivalent" devices are attractive on the basis of competitive cost, compactness, quietness, and higher speed operation. (The microcomputer will operate up to at least 1200 baud.) One device that has proved satisfactory in operation with the present system is the Model 743 data terminal (Texas Instruments, Inc.). Any such teletypewriter "equivalent" device should be chosen with a "mark" parity (rather than either "even" or "odd" parity) option for compatibility with the KIM-1 microcomputer.

Newer data terminals are more commonly equipped with an RS-232-C interface rather than the older 20-mA current loop interface. A data terminal with an RS-232-C interface can also be used in the system, if a current loop/RS-232-C converter is inserted between the KIM-1 and the data terminal. One such converter which has been used without problems is the Model 312A 0566 TTY port interface adapter (United Data Services Company, Inc.)

### Audio Cassette Recorder

The KIM-1 microcomputer program which operates the system of Figure 1 is stored in volatile memory. This means that whenever the microcomputer power is switched off the program is lost and must be reloaded before the next use. The only function of the audio cassette recorder is to provide a convenient means of performing the load operation. Many inexpensive cassette recorders exist that are suitable for this use. A cassette recorder is unnecessary, of course, if a teletypewriter with paper tape punch and reader is chosen as the data terminal, since the program may then be loaded from paper tape.

## SOFTWARE

A flow diagram and listing of the microcomputer program (Program EAA) which controls the operation of the system are included as Appendices. The program is organized into three segments: acquisition, transformation, and output -- each of which is described below.

## Acquisition

The acquisition segment transfers a DVM reading to the microcomputer memory upon command. The EAA control module sends the command via its "Read" signal, which is received on the Interrupt Request line of the microcomputer. This causes the "Data Ready" line from the BCD output of the DVM to be repeatedly scanned by the microcomputer until the appearance of a signal on this line indicates that a new DVM measurement value is available. (Typical DVM measurement frequencies are several per second.) Fourteen data bits, representing $3\frac{1}{2}$ binary coded digits and algebraic sign, are then immediately transferred to the microcomputer memory for storage, and the microcomputer awaits the next "Read" signal. The end of the EAA measurement cycle is recognized by the number of "Read" signals which have occurred.

## Transformation

Upon completion of an EAA cycle, the transformation segment of the program performs the same set of computations that an operator would normally perform to calculate the aerosol size distribution. That is, successive stored readings are subtracted, and the differences are multiplied by a set of pre-stored transformation constants. Any one of three sets of constants may be selected, corresponding to the aerosol size distribution expressed in a number, surface, or volume representation. The transformation constants given in Table 1 were taken from the (inverse) sensitivities for monodisperse aerosols tabulated by Liu et al. (1976). This tabulation is a "smoothed" version of earlier sensitivity data given by Liu and Pui (1975) and judged to be a slightly more realistic calibration than that provided by the earlier unadjusted data. The values in Table 1 and those of Liu et al. (1976) differ by a factor 4, because the quantity $\Delta \log D$ is incorporated into the values of Table 1.

During the subtraction step, two cases of invalid data are recognized by the program: (1) an overrange reading from the DVM, and (2) a DVM reading larger than the preceding one. In either case, the content of the affected size intervals will be arbitrarily set to zero by the program. Since the effect of an overrange condition on the BCD output will vary with the manufacturer, a programming change may be necessary, depending on the DVM used. Similarly, some manufacturers may reverse the normal convention that a positive DVM reading sets the sign bit of the positive-true BCD output. The simple program modifications which will accommodate either of these circumstances are discussed in Section 3.

## Output

The transformed data are printed on the teletypewriter (or equivalent) in a table that lists the 10 values of average particle diameter and the value of the aerosol number, surface, or volume (in 4-place, floating-point, decimal form) corresponding to each diameter. The table is preceded by a character (N, S, or V) which identifies the choice of representation for the aerosol size distribution. A histogram plot can also be printed simultaneously with the

TABLE 1. TRANSFORMATION FACTORS FOR NUMBER, SURFACE, AND VOLUME REPRESENTATION OF EAA MEASUREMENTS*

| D ($\mu$m) | $\Delta N/\Delta \log D \Delta v$ ($cm^{-3}$ $volt^{-1}$) | $\Delta S/\Delta \log D \Delta v$ ($\mu m^2$ $cm^{-3}$ $volt^{-1}$) | $\Delta V/\Delta \log D \Delta v$ ($\mu m^3$ $cm^{-3}$ $volt^{-1}$) |
|---|---|---|---|
| 0.00422 | $0.130 \times 10^{10}$ | $0.720 \times 10^{5}$ | $0.504 \times 10^{2}$ |
| 0.00750 | $0.344 \times 10^{8}$ | $0.608 \times 10^{4}$ | $0.760 \times 10^{1}$ |
| 0.0133 | $0.140 \times 10^{7}$ | $0.780 \times 10^{3}$ | $0.173 \times 10^{1}$ |
| 0.0237 | $0.716 \times 10^{6}$ | $0.127 \times 10^{4}$ | $0.500 \times 10^{1}$ |
| 0.0422 | $0.368 \times 10^{6}$ | $0.206 \times 10^{4}$ | $0.145 \times 10^{2}$ |
| 0.0750 | $0.189 \times 10^{6}$ | $0.334 \times 10^{4}$ | $0.417 \times 10^{2}$ |
| 0.133 | $0.972 \times 10^{5}$ | $0.540 \times 10^{4}$ | $0.120 \times 10^{3}$ |
| 0.237 | $0.496 \times 10^{5}$ | $0.880 \times 10^{4}$ | $0.346 \times 10^{3}$ |
| 0.422 | $0.255 \times 10^{5}$ | $0.143 \times 10^{5}$ | $0.100 \times 10^{4}$ |
| 0.750 | $0.131 \times 10^{5}$ | $0.231 \times 10^{5}$ | $0.289 \times 10^{4}$ |

*N = number, S = surface, V = volume, D = diameter

numerical results as a visual aid. As an example, Figure 2 shows the result of a volume distribution measurement performed on indoor aerosol in our laboratory.

With a teletypewriter operating at only 10 characters/sec, a printout generally cannot be completed before the first DVM reading must be taken in the next EAA cycle. The interrupt structure of the program solves this problem automatically by temporarily suspending output until the DVM reading has been taken.

Data are accumulated automatically and continuously from one EAA cycle after another by the microcomputer program. The operator, however, can choose beforehand to print only one of every N cycles, where N is variable between 1 and 255. Thus, a frequency of measurement is possible from once per 2 min to once per 8½ h. The means by which any of the output options may be selected are discussed in Section 4.

Figure 2. Result of an ambient indoor aerosol measurement, illustrating tabular and histogram outputs. The first column lists the average particle diameter (in μm), while the second and third columns give the corresponding volume distribution values $\Delta V/\Delta \log D$ (in $\mu m^3/cm^3$) as a fraction and power of 10, respectively.

## SECTION 3

## SYSTEM ASSEMBLY

### ELECTRICAL CONNECTIONS

Details of the connections between the KIM-1 microcomputer and the other system components are listed in Table 2. The microcomputer and DVM are joined by a 16-conductor connection (14 data inputs for 3½ binary coded digits and polarity, a "data ready" input, and a ground line). The microcomputer and EAA control module are joined by a connection between the Interrupt Request input of the former and the "Read" terminal of the latter, in addition to a ground connection. (It is essential that the internal jumper of the EAA control module be set to the FAL position to provide a negative-true logic signal at the "Read" terminal.) Two 4-line connections link the data terminal and audio cassette recorder (optional) to the appropriate microcomputer ports. All connections are simple passive ones, since all active circuitry necessary for the microcomputer to transfer information to and from the indicated devices is an integral part of the microcomputer itself. The only connection which does not involve the microcomputer is a coaxial cable from the "Analyzer Current" connector of the EAA to the input of the DVM.

### PROGRAM MODIFICATIONS

Up to three modifications of Program EAA may be required, depending on the baud requirement of the data terminal and the overrange and polarity characteristics of the DVM. Although such changes can be made each time after the program is loaded but before its execution has been started, it is more convenient for the user to produce a new program tape with the changes incorporated permanently. The user should consult the documentation supplied with the KIM-1 for the procedures to generate new paper or magnetic tapes.

#### Data Terminal Baud

Program EAA causes the bit rate (baud) for the system's output device to be set at the beginning of the program's execution. In the current version of the program, the baud is set to 300 (30 characters/sec) in this step. It should be appreciated that any baud setting entered in addresses 17F2 and 17F3 before program execution has begun will be overwritten at this time. If a baud setting different from 300 is required for a specific data terminal, the contents of two KIM-1 addresses must be altered according to Table 3.

TABLE 2. INPUT/OUTPUT CONNECTIONS

| Microcomputer connector pin | I/O port designation | I/O signal |
|---|---|---|
| A-A | | +5 VDC |
| A-14 | PA0 | 1 BIT† |
| A-4 | PA1 | 2 BIT† |
| A-3 | PA2 | 4 BIT† |
| A-2 | PA3 | 8 BIT† |
| A-5 | PA4 | 1 BIT |
| A-6 | PA5 | 2 BIT |
| A-7 | PA6 | 4 BIT |
| A-8 | PA7 | 8 BIT |
| A-9 | PB0 | 1 BIT |
| A-10 | PB1 | 2 BIT |
| A-11 | PB2 | 4 BIT |
| A-12 | PB3 | 8 BIT§ |
| A-13 | PB4 | 1 BIT§ |
| A-16 | PB5 | POLARITY (DVM) |
| A-15 | PB7 | DATA READY (DVM) |
| E-4 | IRQ | READ (EAA CONTROL MODULE) |
| A-R | | TTY KEYBOARD (+) |
| A-S | | TTY PRINTER (+) |
| A-T | | TTY KEYBOARD (-) |
| A-U | | TTY PRINTER (-) |
| A-1* | | GROUND (FOR DVM, EAA READ, AUDIO RECORDER, +5 AND +12VDC) |
| | OPTIONAL: | |
| A-L | | AUDIO IN (EARPHONE JACK) |
| A-M | | AUDIO OUT (MICROPHONE JACK) |
| A-N | | +12 VDC |

*A jumper wire must connect pins A-1 and A-K. Also if the teletypewriter keyboard, instead of the microcomputer keyboard, is used as the input device a jumper wire must connect pins A-21 and A-V.
†Least significant BCD digit from DVM.
§Most significant BCD digit from DVM

TABLE 3. PROGRAM ALTERATIONS TO CHANGE BAUD

| | Baud | | | | | | |
|---|---|---|---|---|---|---|---|
| | 110 | 300* | 600 | 1200 | 2400 | 4800 | 9600 |
| Address | | | | | | | |
| 0105 | 80 | E9 | 74 | 38 | 1A | 06 | 03 |
| 010A | 02 | 00 | 00 | 00 | 00 | 00 | 00 |

*default

In principle the KIM-1 should be able to adjust itself to the requirements of an arbitrary data terminal through a "RESET/RUBOUT" sequence, as described in the KIM-1 documentation. This feature has not proven reliable, however, and hence the alternative procedure given above.

DVM Overrange

Program EAA recognizes an overrange condition of the DVM by comparing the two leading digits of every DVM reading to a prestored characteristic overrange pattern. In the current version of the program, the pattern is "12", corresponding to the DVM overrange reading, "1.200 volts". Other common overrange conditions are 1.999 and 0.000, depending on the DVM manufacturer. For Program EAA to function correctly, the proper two digit pattern for the particular DVM must be entered at address 00E5.

DVM Polarity

Program EAA assumes that a positive signal input to the DVM will set the sign bit of its positive-true output. In the unlikely event that the DVM operates on an opposite convention for the sign bit, the contents of three addresses must be altered, as given in Table 4.

TABLE 4. PROGRAM ALTERATIONS FOR CASE OF UNCONVENTIONAL SIGN BIT

| Address | Normal Content | Altered Content |
|---|---|---|
| 0054 | F0 | D0 |
| 0067 | D0 | F0 |
| 0089 | D0 | F0 |

## SECTION 4

## OPERATING INSTRUCTIONS

### PROCEDURE

1. Power on all system components (EAA, EAA Control, DVM, KIM-1 and Data Terminal).

2. Load Program EAA into KIM-1 from paper tape or audio cassette tape:

   A. Paper Tape

      1. Set teletypewriter to LINE position.

      2. Set teletypewriter baud to 110 by setting KIM-1 address 17F2 = 80 and address 17F3 = 02.

      3. Switch from KIM-1 keyboard to teletypewriter by connecting pins A-21 and A-V, and observe "KIM XXXX XX" to be printed by teletypewriter.

      4. Place leader portion of paper tape in reader. Type L. Move reader switch to START position to begin reading tape.

      5. When the end of the tape is reached, "KIM XX XXXX" will be printed if the read operation has been successful.

      6. Disconnect pins A-21 and A-V to reactivate KIM-1 keyboard.

   B. Audio Cassette Tape

      1. Plug Audio In connector from KIM-1 into Earphone socket of audio cassette recorder. Make certain that Microphone socket is unoccupied. (Conversely, when recording, check that Earphone socket is unoccupied.) Rewind and adjust volume control to about half scale.

      2. Set address 00F1 = 00 and address 17F9 = previously chosen identification number for the program.

3. Select address 1873, and depress KIM-1 "GO" key.

4. Depress Play button on recorder. When the KIM-1 display relights showing "0000 xx," the program has been successfully loaded. Disconnect recorder.

3. For the EAA, adjust all flow rates and check Ionizer Current, Ionizer Voltage and switch in Externally Programmed position.

4. If the DVM has both auto ranging and manual operation modes, select manual mode. Select the "1 Volt DC" scale of the DVM and position the decimal point to the right of the left-most digit (i.e., X.XXX)

5. Depress "CONT. RUN", "ALL", "CURRENT", and "RESET" buttons on EAA Control module.

6. Modify the KIM-1 program according to which output features are desired. (See USER OPTIONS below.) Make any further program changes required. (See SYSTEM ASSEMBLY.)

7. Select address 0100, and depress the KIM-1 "GO" key to begin program execution.

8. Depress "START/STEP" button on EAA Control module.

9. To stop program execution depress the KIM-1 "ST" key.

10. To restart program execution depress "RESET" button on EAA Control module and repeat steps 7 and 8.

USER OPTIONS

Number, Surface and Volume Representations

The contents of addresses 0022 and 0023 determine the output form of the size distribution, as given in Table 5. The output will be preceded by the letter "V", "N", or "S", identifying volume, number, and surface representations, respectively.

TABLE 5. PROGRAM ALTERATIONS FOR CHOICE OF OUTPUT REPRESENTATION

| Address | Content | Output Choice |
|---|---|---|
| 0022 | FE | volume* |
| 0023 | 02 | dV/DlogD, $\mu m^3/cm^3$ |
| 0022 | F6 | number |
| 0023 | 02 | dN/dlogD, $1/cm^3$ |
| 0022 | 06 | surface |
| 0023 | 03 | dS/dlogD, $\mu m^2/cm^3$ |

*default

Output Frequency

The frequency of printed output may be controlled by the content of address 00E4, as given in Table 6. Note that the output frequency is specified as a hexadecimal number. Thus for example if one wishes to output every twentieth cycle, address 00E4 should contain 14 ($14_{16} = 20_{10}$).

TABLE 6. PROGRAM ALTERATION FOR CHOICE OF OUTPUT FREQUENCY

| Address | Content | Effect |
|---|---|---|
| 00E4 | $N_{16}^{*}$ | output occurs once per $N_{16}$ EAA cycles |

*default = 01 (output every cycle)

Suppress Plotting

Histogram plotting to accompany the tabular output of the aerosol size distribution may be selected or omitted, according to the content of addresses 03B4, 03B5 and 03B6, as given in Table 7.

TABLE 7. PROGRAM ALTERATION TO SUPRESS HISTOGRAM PLOTTING

| Address | Content | Effect |
|---|---|---|
| 03B4 | 20 | Plotting selected* |
| 03B5 | D0 | |
| 03B6 | 03 | |
| 03B4 | EA | Plotting suppressed |
| 03B5 | EA | |
| 03B6 | EA | |

*default

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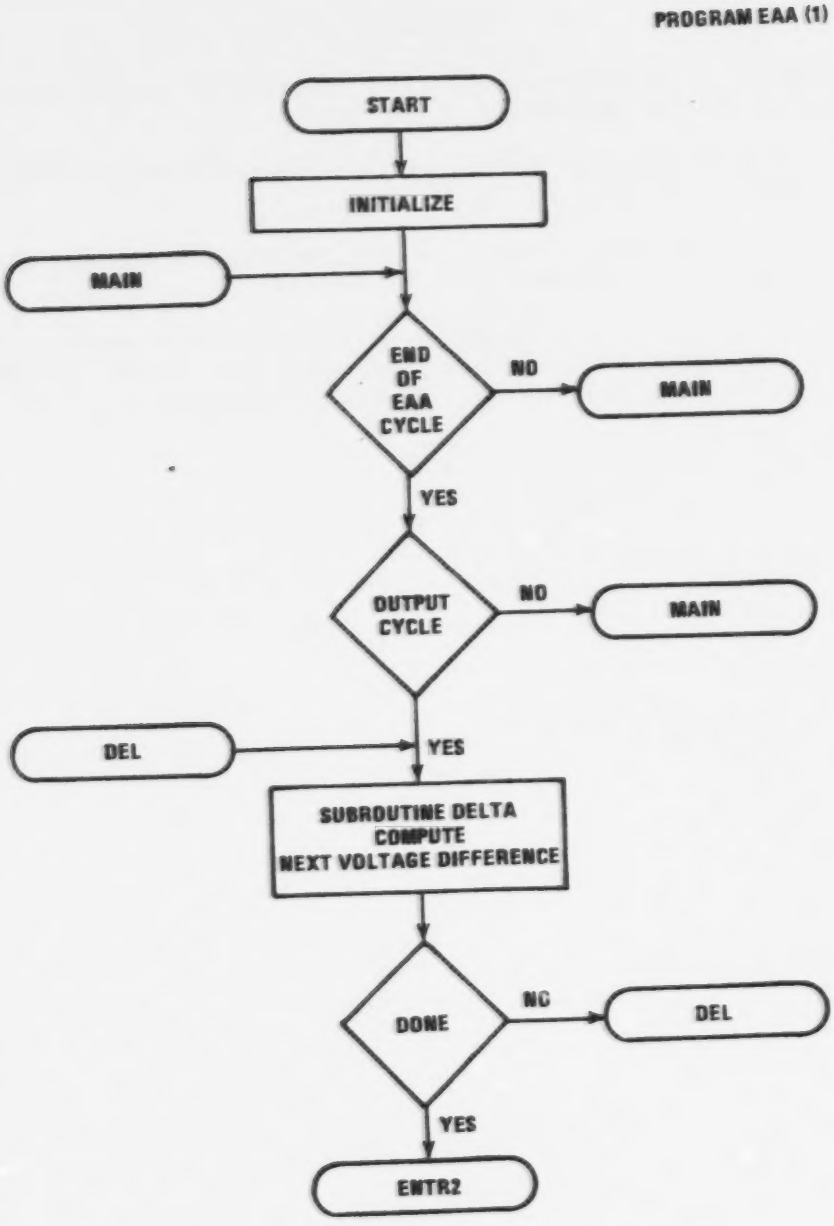
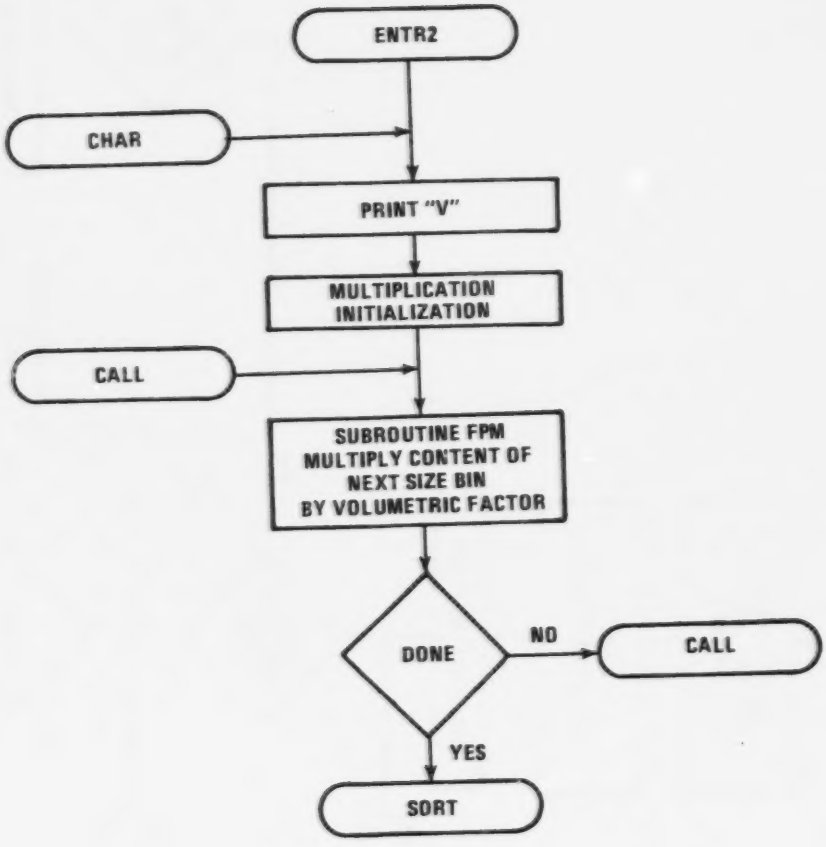
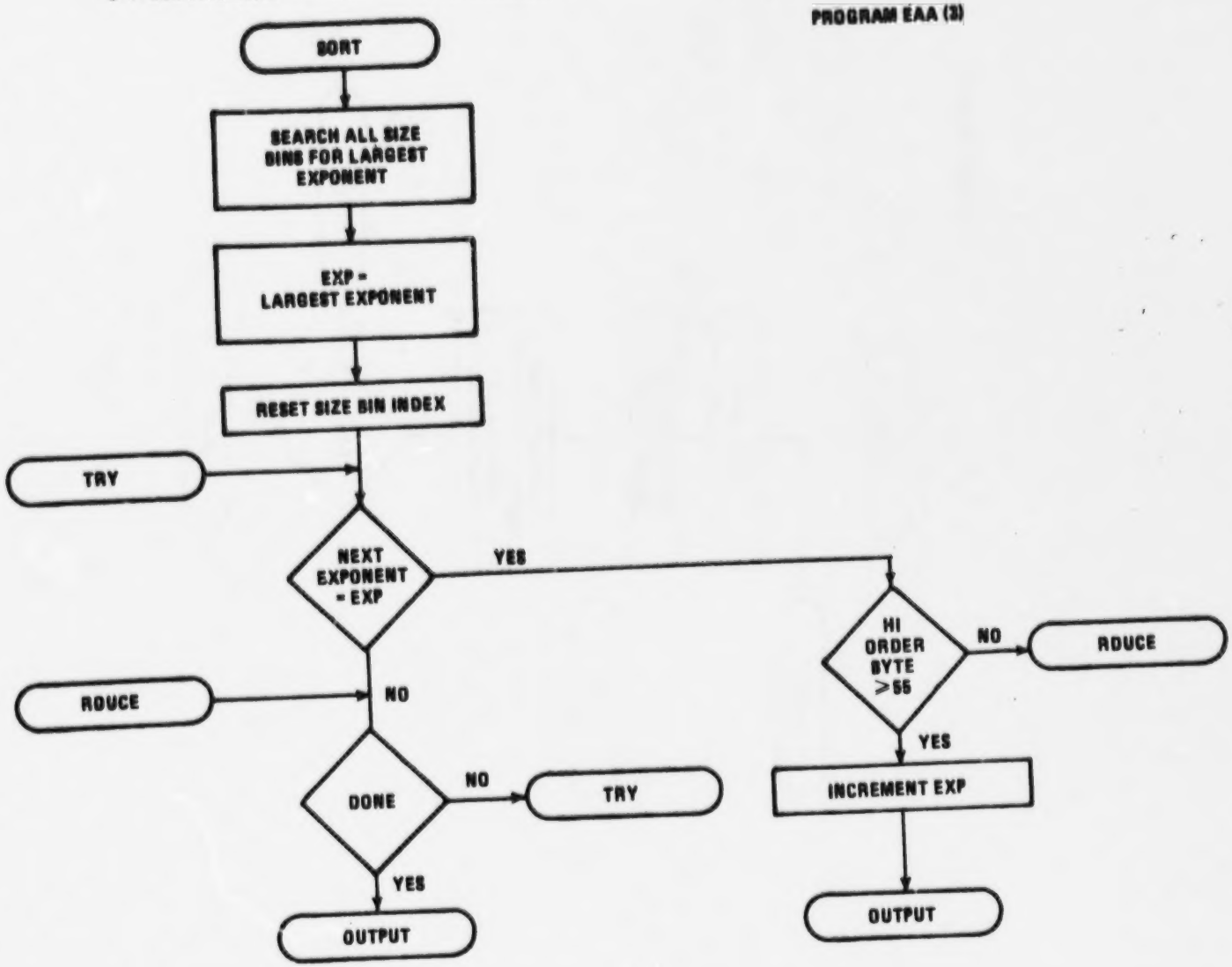
APPENDIX A

PROGRAM EAA FLOW CHART

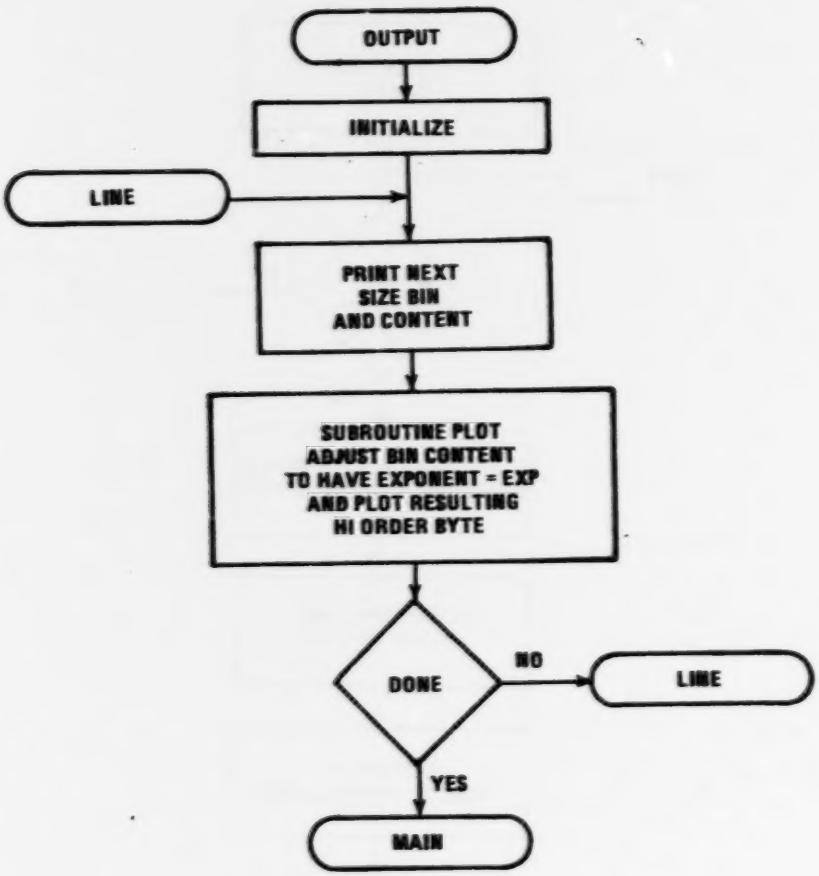


PROGRAM EAA (2)

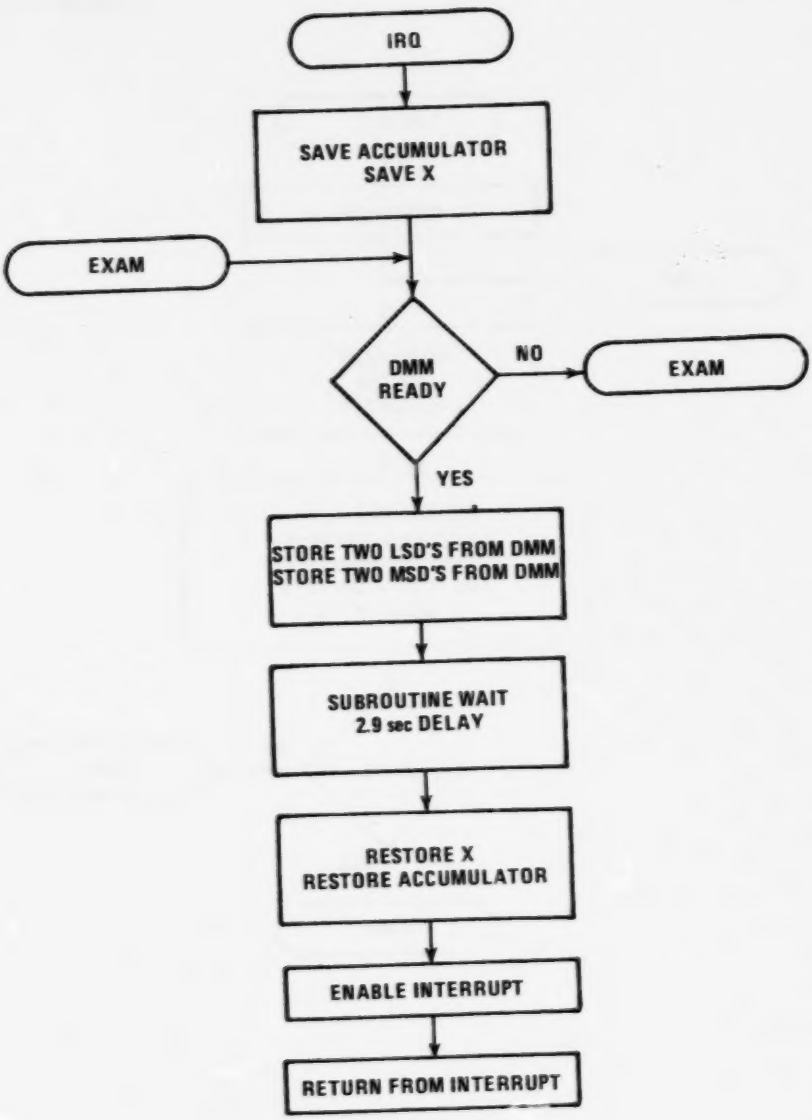



SORT
SEARCH ALL SIZE BINS FOR LARGEST EXPONENT
EXP = LARGEST EXPONENT
RESET SIZE BIN INDEX
TRY
NEXT EXPONENT = EXP
YES
HI ORDER BYTE >55
NO
RDUCE
RDUCE
NO
YES
INCREMENT EXP
DONE
NO
TRY
YES
OUTPUT
OUTPUT

PROGRAM EAA (4)



PROGRAM EAA (5)



## APPENDIX B

## PROGRAM EAA LISTING

| ADDRESS | CODE | LABEL | ASSEMBLY | COMMENT |
|---|---|---|---|---|
| 0000 | A5 2B | MAIN | LDA STEP | MAIN WAITING LOOP |
| 0002 | C9 16 | | CMP #16 | |
| 0004 | D0 FA | | BNE MAIN | END OF ACQUISITION CYCLE? |
| 0006 | A9 00 | | LDA #00 | YES |
| 0008 | 85 2B | | STA STEP | RESET STEP = 0 |
| 000A | C6 29 | | DEC SKIP | |
| 000C | D0 F2 | | BNE MAIN | CYCLE TO BE NEGLECTED? |
| 000E | A5 E4 | | LDA FREQ | NO |
| 0010 | 85 29 | | STA SKIP | RESET SKIP = FREQ |
| 0012 | A0 00 | | LDY #00 | |
| 0014 | A9 1D | | LDA #1D | |
| 0016 | 85 2A | | STA CHAN | CHAN = $29_{10}$ |
| 0018 | F8 | | SED | |
| 0019 | 20 30 00 | DEL | JSR DELTA | COMPUTE DIFFERENCE |
| 001C | C0 14 | | CPY #14 | |
| 001E | D0 F9 | | BNE DEL | ALL DIFFERENCES COMPUTED? |
| 0020 | D8 | | CLD | YES, CLEAR DECIMAL MODE AND |
| 0021 | 4C FE 02 | | JMP ENTR2 | GO TO PRINT ASCII LETTER |
| 0024 | XX XX XX | | | UNUSED |
| 0027 | XX | TIMER | | NINE TEMPORARY STORAGE |
| 0028 | XX | EXP | | ADDRESSES |
| 0029 | XX | SKIP | | |
| 002A | XX | CHAN | | |
| 002B | XX | STEP | | |
| 002C | XX | MLO | | |
| 002D | XX | MHI | | |
| 002E | XX | NLO | | |
| 002F | XX | NHI | | |

| ADDRESS | CODE | LABEL | ASSEMBLY | COMMENT |
|---|---|---|---|---|
| 0030 | C8 | DELTA | INY | SUBTRACTION SUBROUTINE |
| 0031 | B9 1E 02 | | LDA DMM, Y | LOAD 1ST DMM HI ORDER BYTE |
| 0034 | C8 | | INY | |
| 0035 | C8 | | INY | |
| 0036 | 25 E5 | | AND OFFSCL | |
| 0038 | C5 E5 | | CMP OFFSCL | |
| 003A | D0 04 | | BNE NO | 1ST DMM VALUE OVERRANGE? |
| 003C | 88 | | DEY | YES, STORE ZERO |
| 003D | 4C 90 00 | | JMP NUL | |
| 0040 | B9 1E 02 | NO | LDA DMM, Y | NO, LOAD 2ND DMM HI ORDER |
| 0043 | 88 | | DEY | BYTE |
| 0044 | 25 E5 | | AND OFFSCL | |
| 0046 | C5 E5 | | CMP OFFSCL | |
| 0048 | D0 03 | | BNE NORMAL | 2ND DMM VALUE OVERRANGE? |
| 004A | 4C 90 00 | | JMP NUL | YES, STORE ZERO |
| 004D | 88 | NORMAL | DEY | NO, RESTORE Y |
| 004E | B9 1E 02 | | LDA DMM,Y | |
| 0051 | 88 | | DEY | |
| 0052 | 24 E6 | | BIT SIGN | 1ST DMM VALUE POSITIVE? |
| 0054 | F0 19 | | BEQ EXCHNG | NO, GO TO EXCHNG |
| 0056 | A2 00 | | LDX #00 | YES, LOAD 1ST DMM VALUE |
| 0058 | B9 1E 02 | RPT | LDA DMM, Y | INTO MLO AND MHI, |
| 005B | 95 2C | | STA MLO, X | AND 2ND DMM VALUE |
| 005D | C8 | | INY | INTO NLO AND NHI |
| 005E | E8 | | INX | |
| 005F | E0 04 | | CPX #04 | |
| 0061 | D0 F5 | | BNE RPT | |
| 0063 | 88 | | DEY | |
| 0064 | 88 | | DEY | |
| 0065 | 24 E6 | | BIT SIGN | 2ND DMM VALUE POSITIVE? |
| 0067 | D0 22 | | BNE SUBTR | YES, GO TO SUBTR |
| 0069 | 20 C0 00 | ADD | JSR SUM | NO, CALC. ABS(M) + ABS (N) |
| 006C | 4C A3 00 | | JMP STORE | |

```
ADDRESS  CODE       LABEL    ASSEMBLY        COMMENT

006F     B9 1E 02   EXCHNG   LDA DMM, Y      LOAD 1ST DMM VALUE
0072     85 2E               STA NLO         INTO NLO AND NHI
0074     C8                  INY
0075     B9 1E 02            LDA DMM, Y
0078     85 2F               STA NHI
007A     C8                  INY
007B     B9 1E 02            LDA DMM, Y      LOAD 2ND DMM VALUE
007E     85 2C               STA MLO         INTO MLO AND MHI
0080     C8                  INY
0081     B9 1E 02            LDA DMM, Y
0084     85 2D               STA MHI
0086     88                  DEY
0087     24 E6               BIT SIGN        2ND DMM VALUE POSITIVE
0089     D0 05               BNE NUL         YES, GO TO NUL
008B     20 D1 00   SUBTR     JSR DIFF        NO, CALC. ABS(M) - ABS(N)
008E     B0 13               BCS STORE       POSITIVE RESULT?
0090     A6 2A      NUL      LDX CHAN        NO,
0092     A9 00               LDA #00         STORE ZERO
0094     9D 00 02            STA DMMDIF, X
0097     CA                  DEX
0098     9D 00 02            STA DMMDIF, X
009B     CA                  DEX
009C     9D 00 02            STA DMMDIF, X
009F     CA                  DEX
00A0     86 2A               STX CHAN
00A2     60                  RTS             SUBROUTINE RETURN
00A3     A6 2A      STORE    LDX CHAN        YES,
00A5     A5 2D               LDA MHI         STORE RESULT:
00A7     9D 00 02            STA DMMDIF, X   HI ORDER BYTE
00AA     CA                  DEX
00AB     A5 2C               LDA MLO
00AD     9D 00 02            STA DMMDIF, X   LO ORDER BYTE
00B0     CA                  DEX
```

```
ADDRESS  CODE        LABEL   ASSEMBLY          COMMENT

00B1     A9 01               LDA #01
00B3     9D 00 02            STA DMMDIF, X     EXPONENT
00B6     CA                  DEX
00B7     86 2A               STX CHAN
00B9     60                  RTS               SUBROUTINE RETURN
00BA     78          CR      SEI               SUBROUTINE FOR
00BB     20 2F 1E            JSR CRLF          CARRIAGE RETURN, LINE FEED
00BE     58                  CLI
00BF     60                  RTS               SUBROUTINE RETURN
00C0     20 E1 02    SUM     JSR MASK          SUBROUTINE TO
00C3     18                  CLC               CALC. ABS(M) + ABS(N)
00C4     A5 2C               LDA MLO
00C6     65 2E               ADC NLO
00C8     85 2C               STA MLO
00CA     A5 2D               LDA MHI
00CC     65 2F               ADC NHI
00CE     85 2D               STA MHI
00D0     60                  RTS               SUBROUTINE RETURN
00D1     20 E1 02    DIFF    JSR MASK          SUBROUTINE TO
00D4     38                  SEC               CALC. ABS(M) - ABS(N)
00D5     A5 2C               LDA MLO
00D7     E5 2E               SBC NLO
00D9     85 2C               STA MLO
00DB     A5 2D               LDA MHI
00DD     E5 2F               SBC NHI
00DF     85 2D               STA MHI
00E1     60                  RTS               SUBROUTINE RETURN
00E2     XX                                    UNUSED
00E3     XX                                    UNUSED
```

| ADDRESS | CODE | LABEL | ASSEMBLY | COMMENT |
|---|---|---|---|---|
| 00E4 | 01 | FREQ | | FREQUENCY OF EAA PRINTOUT |
| 00E5 | 12 | OFFSCL | | DMM OVERRANGE MASK |
| 00E6 | 20 | SIGN | | DMM SIGN BIT MASK |
| 00E7 | XX | TEMPA | | TWO TEMPORARY STORAGE |
| 00E8 | XX | TEMPB | | ADDRESSES |
| 00E9 | XX | PLIERPNTL/COUNTER | | THREE POINTER ADDRESSES |
| 00EA | 02 | PLIERPNTH | | FOR MULTIPLY SUBROUTINE |
| 00EB | XX | CANDPNTL | | |
| 00EC | 02 | CANDPNTH | | |
| 00ED | XX | PRODPNTL | | |
| 00EE | 02 | PRODPNTH | | |
| 00EF | XX XX XX | | | ADDRESSES 00EF- |
| 00F2 | XX XX XX | | | 00FF NOT AVAILABLE FOR |
| 00F5 | XX XX XX | | | USER PROGRAMS |
| 00F8 | XX XX XX | | | |
| 00FB | XX XX XX | | | |
| 00FE | XX XX | | | |

```
ADDRESS  CODE       LABEL   ASSEMBLY    COMMENT

0100     D8         START   CLD         STARTING ADDRESS, CLEAR
0101     A2 FF              LDX #FF     DECIMAL MODE
0103     9A                 TXS         INITIALIZE STACK
0104     A9 E9              LDA #E9     SET BAUD RATE = 300
0106     8D F2 17           STA 17F2
0109     A9 00              LDA #00
010B     8D F3 17           STA 17F3
010E     20 2F 1E           JSR CRLF    CARRIAGE RETURN, LINE FEED
0111     20 2F 1E           JSR CRLF
0114     EA                 NOP
0115     A9 00              LDA #00     DEFINE PORTS A & B
0117     8D 01 17           STA 1701    AS ALL INPUTS
011A     8D 03 17           STA 1703
011D     8D FA 17           STA 17FA    SET UP INTERRUPT
0120     A9 1C              LDA #1C     VECTOR FOR NMI
0122     8D FB 17           STA 17FB
0125     A9 AC              LDA #AC     SET UP INTERRUPT
0127     8D FE 17           STA 17FE    VECTOR FOR IRQ
012A     A9 02              LDA #02
012C     8D FF 17           STA 17FF
012F     A5 E4              LDA FREQ    INITIALIZE SKIP
0131     85 29              STA SKIP
0133     A9 00              LDA #00
0135     85 2B              STA STEP    SET STEP = 0
0137     58                 CLI         ENABLE IRQ
0138     4C 00 00           JMP MAIN    BEGIN DATA ACQUISITION
```

```
ADDRESS  CODE        LABEL     ASSEMBLY            COMMENT

013B     48          FPM       PHA                 DECIMAL FLOATING POINT
013C     08                    PHP                 MULTIPLY SUBROUTINE
013D     86 E7                 STX TEMPA           (DECIMAL MODE
013F     84 E8                 STY TEMPB           PREVIOUSLY SET)
0141     A9 03                 LDA #03
0143     8D E4 01              STA CNTSHIFT        INITIALIZE SHIFT COUNTER.
0146     A0 06                 LDY #06             SET TO ZERO:
0143     A9 00                 LDA #00             CANDSRH, CANDSRL,
014A     99 E7 01    AGN       STA CNTEXP,Y        PROD1, PROD2,
014D     88                    DEY                 PROD3, PROD4,
014E     10 FA                 BPL AGN             CNTEXP.
0150     A0 02                 LDY #02             LOAD PLIERH
0152     B1 E9       LDP       LDA (PLIERPNTL),Y   AND PLIERL
0154     88                    DEY                 INTO RESIDENT
0155     99 E5 01              STA PLIERL,Y        STORAGE
0158     D0 F8                 BNE LDP
015A     A0 01                 LDY #01             LOAD CANDL
015C     B1 EB                 LDA (CANDPNTL),Y    AND CANDH
015E     8D EF 01              STA CANDL           INTO RESIDENT
0161     C8                    INY                 STORAGE
0162     B1 EB                 LDA (CANDPNTL),Y
0164     8D EE 01              STA CANDH
0167     AD E5 01    CKPLIER   LDA PLIERL          CHECK 4 LSB'S
016A     29 0F                 AND #0F             OF PLIERL
016C     F0 13                 BEQ DECCNTSHIFT
016E     A8                    TAY                 Y = ADDITION COUNTER
016F     18          SETX      CLC                 ADD ALL 4 BYTES
0170     A2 03                 LDX #03             OF CAND TO PROD
0172     BD EC 01    SUM       LDA CANDSRH,X
0175     7D E8 01              ADC PROD1,X
0178     9D E8 01              STA PROD1,X
017B     CA                    DEX
```

```
ADDRESS  CODE       LABEL          ASSEMBLY              COMMENT

017C     10 F4                     BPL SUM
017E     88                       DEY                   REPEAT ADDITIONS
017F     D0 EE                    BNE SETX              FOR Y TIMES.
0181     CE E4 01   DECCNTSHIFT   DEC CNTSHIFT          BRANCH IF ALL 4 DIGITS
0184     30 16                    BMI LJD               OF PLIER HAVE BEEN USED
0186     A0 04                    LDY #04               Y = 4 BIT COUNTER
0188     A2 03      NEXTDIG       LDX #03               X = 4 BYTE COUNTER
018A     18                       CLC                   SHIFT CAND
018B     3E EC 01   ROCAND       ROL CANDSRH,X         LEFT 1 BIT
018E     CA                       DEX                   REPEAT FOR ALL 4
018F     10 FA                    BPL ROCAND            BYTES
0191     4E E6 01                 LSR PLIERH            SHIFT PLIER
0194     6E E5 01                 ROR PLIERL            RIGHT 1 BIT
0197     88                       DEY                   REPEAT FOR 4
0198     D0 EE                    BNE NEXTDIG           BITS.
019A     F0 CB                    BEQ CKPLIER
019C     A0 00      LJD           LDY #00
019E     B1 E9      ADDEXP        LDA (PLIERPNTL),Y     ADD EXPONENTS
01A0     18                       CLC                   OF PLIER AND
01A1     71 EB                    ADC (CANDPNTL),Y      CAND
01A3     8D E7 01                 STA CNTEXP
01A6     A9 F0      CKMSD         LDA #F0               CHECK 4 MSB'S
01A8     2C E8 01                 BIT PROD1             OF PROD
01AB     D0 1E                    BNE STOREXP           BRANCH IF ≠ 0
01AD     A0 04                    LDY #04               4 BITS FOR EACH BCD
01AF     18         DIGSHIFT      CLC                   DIGIT
01B0     A2 03                    LDX #03               PROD CONTAINS 4 BYTES
01B2     3E E8 01   BITSHIFT      ROL PROD1,X           SHIFT PROD LEFT
01B5     CA                       DEX                   1 BIT. REPEAT FOR
01B6     10 FA                    BPL BITSHIFT          ALL 4 BYTES
01B8     88                       DEY                   REPEAT FOR 4 BITS
01B9     D0 F4                    BNE DIGSHIFT
01BB     38         DECEXP        SEC                   DECREMENT EXPONENT
```

| ADDRESS | CODE | LABEL | ASSEMBLY | COMMENTS |
|---|---|---|---|---|
| 01BC | AD E7 01 | | LDA CNTEXP | FOR EACH DIGIT |
| 01BF | E9 01 | | SBC #01 | SHIFTED |
| 01C1 | 8D E7 01 | | STA CNTEXP | |
| 01C4 | D0 E0 | | BNE CKMSD | |
| 01C6 | F0 03 | | BEQ STOREXP | |
| 01C8 | XX XX XX | | | UNUSED |
| 01CB | AD E7 01 | STOREXP | LDA CNTEXP | (Y = 0) |
| 01CE | 91 ED | | STA (PRODPNTL),Y | EXPONENT STORED AT LOWEST |
| 01D0 | A0 02 | | LDY #02 | ADDRESS |
| 01D2 | AD E8 01 | | LDA PROD1 | |
| 01D5 | 91 ED | | STA (PRODPNTL),Y | HI STORED AT HIGHEST ADDRESS |
| 01D7 | 88 | | DEY | |
| 01D8 | AD E9 01 | | LDA PROD2 | |
| 01DB | 91 ED | | STA (PRODPNTL),Y | LO STORED AT MIDDLE ADDRESS |
| 01DD | A6 E7 | | LDX TEMPA | |
| 01DF | A4 E8 | | LDY TEMPB | |
| 01E1 | 28 | | PLP | |
| 01E2 | 68 | | PLA | |
| 01E3 | 60 | | RTS | RETURN FROM SUBROUTINE |
| 01E4 | XX | CNTSHIFT | | TWELVE TEMPORARY |
| 01E5 | XX | PLIERL | | STORAGE ADDRESSES |
| 01E6 | XX | PLIERH | | USED BY MULTIPLY |
| 01E7 | XX | CNTEXP | | SUBROUTINE |
| 01E8 | XX | PROD1 | | |
| 01E9 | XX | PROD2 | | |
| 01EA | XX | PROD3 | | |
| 01EB | XX | PROD4 | | |
| 01EC | XX | CANDSRH | | |
| 01ED | XX | CANDSRL | | |
| 01EE | XX | CANDH | | |
| 01EF | XX | CANDL | | |
| 01F0 | XX XX XX | | | UNUSED |
| 01F3 | XX XX XX | | | UNUSED |

| ADDRESS | CODE | LABEL | ASSEMBLY | COMMENTS |
|---|---|---|---|---|
| 01F6 | XX XX XX | | | UNUSED |
| 01F9 | XX XX XX | | | UNUSED |
| 01FC | XX XX | | | UNUSED |
| 01FE | XX | | | RESERVED FOR |
| 01FF | XX | STACK | | STACK OPERATION |

| ADDRESS | CODE | LABEL | ASSEMBLY | COMMENT |
|---|---|---|---|---|
| 0200 | XX XX XX | DMMDIF | | ADDRESSES 0200-021D |
| . | . . . | | | CONTAIN COMPUTED |
| . | . . . | | | DIFFERENCES OF |
| . | . . . | | | SUCCESSIVE DMM READINGS |
| . | . . . | | | STORED AS $10_{10}$ THREE |
| . | . . . | | | BYTE (EXPONENT, LO |
| . | . . . | | | ORDER, HI ORDER) |
| 021B | XX XX XX | | | BCD NUMBERS. |
| 021E | XX XX | DMM | | ADDRESSES 021E-0233 |
| . | . . | | | CONTAIN SUCCESSIVE |
| . | . . | | | DMM READINGS FROM |
| . | . . | | | AN EAA CYCLE, |
| . | . . | | | STORED AS $11_{10}$ TWO |
| . | . . | | | BYTE (LO ORDER, HI |
| 0232 | XX XX | | | ORDER) BCD NUMBERS. |

| ADDRESS | CODE | LABEL | ASSEMBLY | COMMENT |
|---|---|---|---|---|
| 0234 | 04 90 28 | VOLUME | | VOLUME TRANSFORMATION |
| 0237 | 04 00 10 | | | FACTORS FOR EACH SIZE |
| 023A | 03 60 34 | | | BIN, STORED IN REVERSE |
| 023D | 03 00 12 | | | DECIMAL FLOATING POINT |
| 0240 | 02 70 41 | | | FORMAT. FOR EXAMPLE, |
| 0243 | 02 50 14 | | | THE FIRST FACTOR IS |
| 0246 | 01 00 50 | | | $0.2890 \times 10^4$ |
| 0249 | 01 30 17 | | | |
| 024C | 01 00 76 | | | |
| 024F | 02 40 50 | | | |
| 0252 | 05 10 23 | SURFACE | | SURFACE TRANSFORMATION |
| 0255 | 05 30 14 | | | FACTORS. THE |
| 0258 | 04 00 88 | | | FIRST FACTOR IS |
| 025B | 04 00 54 | | | $0.2310 \times 10^5$ |
| 025E | 04 40 33 | | | |
| 0261 | 04 60 20 | | | |
| 0264 | 04 70 12 | | | |
| 0267 | 03 00 78 | | | |
| 026A | 04 80 60 | | | |
| 026D | 05 00 72 | | | |
| 0270 | 05 10 13 | NUMBER | | NUMBER TRANSFORMATION |
| 0273 | 05 50 25 | | | FACTORS. THE FIRST |
| 0276 | 05 60 49 | | | FACTOR IS |
| 0279 | 05 20 97 | | | $0.1310 \times 10^5$ |
| 027C | 06 90 18 | | | |
| 027F | 06 80 36 | | | |
| 0282 | 06 60 71 | | | |
| 0285 | 07 00 14 | | | |
| 0288 | 08 40 34 | | | |
| 028B | 10 00 13 | | | |

| ADDRESS | CODE | LABEL | ASSEMBLY | COMMENT |
|---|---|---|---|---|
| 028E | 30 35 37 | TABLE | | AVE. PARTICLE DIA. |
| 0291 | 32 32 34 | | | (IN NANOMETERS) FOR |
| 0294 | 37 33 32 | | | EACH SIZE BIN, STORED |
| 0297 | 33 33 31 | | | IN REVERSE ASCII FORMAT. |
| 029A | 35 37 30 | | | FOR EXAMPLE, THE FIRST |
| 029D | 32 34 30 | | | ENTRY CORRESPONDS TO 750 |
| 02A0 | 34 32 30 | | | WITH 30 = 0, 35 = 5, 37 = 7 |
| 02A3 | 33 31 30 | | | |
| 02A6 | 38 30 30 | | | |
| 02A9 | 34 30 30 | | | |

```
ADDRESS  CODE       LABEL   ASSEMBLY        COMMENT

02AC     48         IRQ     PHA             INTERRUPT BY EAA READ
02AD     8A                 TXA             SAVE A
02AE     48                 PHA             SAVE X
02AF     A6 2B              LDX STEP        X = STEP
02B1     AD 02 17   EXAM    LDA 1702
02B4     10 FB              BPL EXAM        IS DMM READY?
02B6     AD 00 17           LDA 1700        YES, STORE 2 LSD'S
02B9     9D 1E 02           STA DMM, X      FROM DMM
02BC     E8                 INX
02BD     AD 02 17           LDA 1702        STORE 2 MSD'S
02C0     9D 1E 02           STA DMM, X      FROM DMM
02C3     E8                 INX
02C4     A9 FF              LDA #FF         DELAY FOR
02C6     20 D0 02           JSR WAIT        256 x 11.264 = 2884 MSEC.
02C9     86 2B              STX STEP        STEP = X
02CB     68                 PLA
02CC     AA                 TAX             RESTORE X
02CD     68                 PLA             RESTORE A
02CE     58                 CLI             ENABLE IRQ
02CF     40                 RTI             INTERRUPT RETURN
```

| ADDRESS | CODE | LABEL | ASSEMBLY | COMMENT |
|---|---|---|---|---|
| 02D0 | 85 27 | WAIT | STA TIMER | WAITING SUBROUTINE |
| 02D2 | A9 0A | AGAIN | LDA #0A | SET CLOCK FOR |
| 02D4 | 8D 07 17 | | STA 1707 | 11 x 1.024 = 11.264 MSEC. |
| 02D7 | AD 07 17 | FLAG | LDA 1707 | REMAIN IN SUBROUTINE |
| 02DA | F0 FB | | BEQ FLAG | UNTIL (TIMER) X 11.264 MSEC |
| 02DC | C6 27 | | DEC TIMER | HAS PASSED |
| 02DE | D0 F2 | | BNE AGAIN | |
| 02E0 | 60 | | RTS | SUBROUTINE RETURN |
| 02E1 | A5 2D | MASK | LDA MHI | MASKING SUBROUTINE |
| 02E3 | 29 1F | | AND #1F | SET 3 MSB'S OF |
| 02E5 | 85 2D | | STA MHI | MHI AND NHI TO |
| 02E7 | A5 2F | | LDA NHI | ZERO |
| 02E9 | 29 1F | | AND #1F | |
| 02EB | 85 2F | | STA NHI | |
| 02ED | 60 | | RTS | SUBROUTINE RETURN |
| 02EE | 78 | CH | SEI | SUBROUTINE TO |
| 02EF | 20 A0 1E | | JSR OUTCH | OUTPUT CHARACTER |
| 02F2 | 58 | | CLI | |
| 02F3 | 60 | | RTS | SUBROUTINE RETURN |
| 02F4 | XX XX | | | UNUSED |

| ADDRESS | CODE | LABEL | ASSEMBLY | COMMENT |
|---|---|---|---|---|
| 02F6 | A9 70 | ENTR1 | LDA #70 | MULTIPLY ROUTINE |
| 02F8 | 85 E9 | | STA E9 | LOAD PLIERPNTL WITH LO ORDER |
| 02FA | A9 4E | | LDA #4E | ADDRESS OF NUMBER |
| 02FC | D0 0E | | BNE CHAR | ASCII "N" |
| 02FE | A9 34 | ENTR2 | LDA #34 | LOAD PLIERPNTL WITH LO ORDER |
| 0300 | 85 E9 | | STA E9 | ADDRESS OF VOLUME |
| 0302 | A9 56 | | LDA #56 | ASCII "V" |
| 0304 | D0 06 | | BNE CHAR | |
| 0306 | A9 52 | ENTR3 | LDA #52 | LOAD PLIERPNTL WITH LO ORDER |
| 0308 | 85 E9 | | STA E9 | ADDRESS OF SURFACE |
| 030A | A9 53 | | LDA #53 | ASCII "S" |
| 030C | 20 A0 1E | CHAR | JSR OUTCH | PRINT "V" OR "S" OR "N" |
| 030F | 20 2F 1E | | JSR CRLF | CARRIAGE RETURN, LINE FEED |
| 0312 | A9 00 | | LDA #00 | INITIALIZE: |
| 0314 | 85 EB | | STA EB | CANDPNTL AND |
| 0316 | 85 ED | | STA ED | PRODPNTL |
| 0318 | A0 0A | | LDY #0A | $10_{10}$SIZE BINS |
| 031A | F8 | CALL | SED | SET DECIMAL MODE |
| 031B | 20 3B 01 | | JSR FPM | MULTIPLY |
| 031E | D8 | | CLD | CLEAR DECIMAL MODE |
| 031F | 88 | | DEY | |
| 0320 | D0 03 | | BNE #03 | IF ALL BINS DONE |
| 0322 | 4C 39 03 | | JMP SORT | GO TO SORT |
| 0325 | A2 04 | | LDX #04 | IF NOT DONE, |
| 0327 | F6 E9 | INCP | INC E9,X | INCREMENT |
| 0329 | F6 E9 | | INC E9,X | PLIERPNTL, |
| 032B | F6 E9 | | INC E9,X | CANDPNTL, AND |
| 032D | CA | | DEX | PRODPNTL |
| 032E | CA | | DEX | THREE TIMES |
| 032F | 10 F6 | | BPL INCP | |
| 0331 | 30 E7 | | BMI CALL | DO NEXT MULTIPLICATION |

| ADDRESS | CODE | LABEL | ASSEMBLY | COMMENT |
|---|---|---|---|---|
| 0333 | 78 | SP | SEI | SUBROUTINE TO |
| 0334 | 20 9E 1E | | JSR OUTSP | OUTPUT SPACE |
| 0337 | 58 | | CLI | |
| 0338 | 60 | | RTS | SUBROUTINE RETURN |

| ADDRESS | CODE | LABEL | ASSEMBLY | COMMENT |
|---|---|---|---|---|
| 0339 | A9 00 | SORT | LDA #00 | ROUTINE TO FIND |
| 033B | 85 28 | | STA EXP | LARGEST EXPONENT |
| 033D | A2 1B | | LDX #1B | $1B_{16}$ = 10 BINS X 3 - 3 |
| 033F | BD 00 02 | TEST | LDA 0200,X | LOAD NEXT EXPONENT |
| 0342 | C5 28 | | CMP EXP | |
| 0344 | 90 02 | | BCC DECR | STORE IF LARGER |
| 0346 | 85 28 | | STA EXP | THAN PREVIOUS EXP'S |
| 0348 | CA | DECR | DEX | |
| 0349 | CA | | DEX | |
| 034A | CA | | DEX | |
| 034B | 10 F2 | | BPL TEST | DONE? |
| 034D | A2 1B | | LDX #1B | YES, RESET X |
| 034F | BD 00 02 | TRY | LDA 0200,X | LOAD NEXT EXPONENT |
| 0352 | C5 28 | | CMP EXP | EXPONENT MAXIMUM? |
| 0354 | D0 10 | | BNE RDUCE | NO, GO TO RDUCE |
| 0356 | E8 | | INX | |
| 0357 | E8 | | INX | |
| 0358 | BD 00 02 | | LDA 0200, X | YES, LOAD HI ORDER |
| 035B | CA | | DEX | BYTE |
| 035C | CA | | DEX | |
| 035D | C9 55 | | CMP #55 | $55_{10}$ = MAX. ORDINATE |
| 035F | 90 05 | | BCC RDUCE | MAX. ORDINATE EXCEEDED? |
| 0361 | E6 28 | | INC EXP | YES |
| 0363 | 4C 78 03 | | JMP OUTPUT | |
| 0366 | CA | RDUCE | DEX | NO |
| 0367 | CA | | DEX | |
| 0368 | CA | | DEX | |
| 0369 | 10 E4 | | BPL TRY | DONE? |
| 036B | 4C 78 03 | | JMP OUTPUT | YES |
| 036E | XX XX XX | | | UNUSED |
| 0371 | XX XX XX | | | UNUSED |
| 0374 | XX XX XX | | | UNUSED |
| 0377 | XX | | | UNUSED |

| ADDRESS | CODE | LABEL | ASSEMBLY | COMMENT |
|---|---|---|---|---|
| 0378 | A9 00 | OUTPUT | LDA #00 | OUTPUT ROUTINE |
| 037A | 85 ED | | STA ED | INITIALIZE DATPNTL |
| 037C | A9 1D | | LDA #1D | $1D_{16} = 29_{10}$ = |
| 037E | 85 E7 | | STA TEMPA | 3 x NO. OF BINS - 1 |
| 0380 | 85 E8 | | STA TEMPB | |
| 0382 | A9 03 | LINE | LDA #03 | |
| 0384 | 85 E9 | | STA COUNTER | 3 CHARACTER COUNTER |
| 0386 | A9 2E | | LDA #2E | |
| 0388 | 20 EE 02 | | JSR CH | |
| 038B | A6 E7 | ASCII | LDX TEMPA | |
| 038D | BD 8E 02 | | LDA TABLE, X | ASCII TABLE ADDRESS = 028E |
| 0390 | 20 EE 02 | | JSR CH | PRINT NEXT ASCII CHARACTER |
| 0393 | C6 E7 | | DEC TEMPA | |
| 0395 | C6 E9 | | DEC COUNTER | |
| 0397 | D0 F2 | | BNE ASCII | PROCEED AFTER 3 CHARACTERS |
| 0399 | 20 33 03 | | JSR SP | |
| 039C | 20 33 03 | | JSR SP | PRINT 2 SPACES |
| 039F | A9 2E | | LDA #2E | ASCII "." |
| 03A1 | 20 EE 02 | | JSR CH | PRINT "." |
| 03A4 | 20 C4 03 | | JSR OUTBYT | PRINT HI ORDER BYTE |
| 03A7 | A5 2D | | LDA MHI | STORE HI ORDER BYTE IN NHI |
| 03A9 | 85 2F | | STA NHI | |
| 03AB | 20 C4 03 | | JSR OUTBYT | PRINT LO ORDER BYTE |
| 03AE | 20 33 03 | | JSR SP | PRINT SPACE |
| 03B1 | 20 C4 03 | | JSR OUTBYT | PRINT EXPONENT |
| 03B4 | 20 D0 03 | | JSR PLOT | PLOT HI ORDER BYTE |
| 03B7 | 20 BA 00 | | JSR CR | CARRIAGE RETURN, LINE FEED |
| 03BA | A5 E8 | | LDA TEMPB | |
| 03BC | 10 C4 | | BPL LINE | PROCEED AFTER $10_{10}$ LINES |
| 03BE | 20 BA 00 | | JSR CR | CARRIAGE RETURN, LINE FEED |
| 03C1 | 4C 00 00 | | JMP MAIN | RETURN TO MAIN WAITING LOOP |
| 03C4 | A4 E8 | OUTBYT | LDY TEMPB | SUBROUTINE TO |

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ADDRESS  CODE       LABEL     ASSEMBLY        COMMENT

03C6     B1 ED              LDA (ED), Y     PRINT ONE BYTE
03C8     85 2D              STA MHI
03CA     20 FA 03           JSR BT
03CD     C6 E8              DEC TEMPB
03CF     60                 RTS             SUBROUTINE RETURN
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ADDRESS  CODE       LABEL    ASSEMBLY      COMMENT

03D0     F8         PLOT     SED           SUBROUTINE TO PLOT
03D1     38                  SEC           HI ORDER BYTE (NHI)
03D2     A5 28               LDA EXP       COMPARE EXPONENT
03D4     E5 2D               SBC MHI       WITH MAX. VALUE
03D6     F0 0D               BEQ ORDNAT    IF NON-ZERO STORE
03D8     85 2D               STA MHI       DIFFERENCE IN MHI
03DA     A0 04      SETY     LDY #04       SHIFT HI ORDER BYTE
03DC     46 2F      RTSHFT   LSR NHI       4 BITS RIGHT (MHI)
03DE     88                  DEY           TIMES
03DF     D0 FB               BNE RTSHFT
03E1     C6 2D               DEC MHI
03E3     D0 F5               BNE SETY
03E5     D8         ORDNAT   CLD           CLEAR DECIMAL MODE
03E6     A9 2A               LDA #2A       ASCII "*"
03E8     20 EE 02            JSR CH        PRINT "*"
03EB     F8                  SED           SET DECIMAL MODE
03EC     38                  SEC
03ED     A5 2F               LDA NHI       DECREMENT HI ORDER
03EF     E9 01               SBC #01       BYTE BY ONE
03F1     90 05               BCC EXIT      RESULT NEGATIVE?
03F3     85 2F               STA NHI       NO, PRINT AGAIN
03F5     4C E5 03            JMP ORDNAT
03F8     D8         EXIT     CLD           YES, CLEAR DECIMAL MODE
03F9     60                  RTS           SUBROUTINE RETURN
03FA     78         BT       SEI           SUBROUTINE TO
03FB     20 3B 1E            JSR PRTBYT    PRINT BYTE
03FE     58                  CLI
03FF     60                  RTS           SUBROUTINE RETURN
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